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DETERMINATION OF HOT AND COLD START PERCENTAGES IN NEW JERSEY

FINAL REPORT

by

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16. Abstract

All major federally funded road construction and reconstruction requires an enviornmental impact statement which includes a prediction of air quality resulting from projected traffic changes. Part of this prediction is a correction based on the percentages of cars and light trucks operating in the "Hot Start" and "Cold Start" conditions (by EPA definitions). This study was undertaken to determine these percentages for the various classifications of New Jersey roads.

Data was collected at field sites which were representative of each of the six functional roadway classifications. With the driver's permission engine oil and coolant temperatures were measured and engine run time estimates were obtained from the driver. The data was analyzed to determine the percentages of hot, cold, and stabilized engines.

This report summarizes the Literature Search, the Vehicle Operating Experiment, the Equipment Selection, the Sampling Scheme Development and the Data Collection, Reduction and Analysis. Procedures and results are listed, conclusions drawn and recommendations made.

The percent of hot and cold starts during peak hours ranged from 3 to 10.6 and from 36.9 to 64, respectively, for all roadway classifications.

The percent of hot and cold starts during off-peak hours ranged from 8.6 to 30.8 and 23.2 to 34.2, respectively, for all roadway classifications.

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CONCLUSIONS

STUDY CONCLUSIONS

The proportions of vehicles operating in the "hot and cold start" conditions on the nation's roadways cannot be easily determined. Estimates of hot and cold start percentages must be made on the basis of the functional classification of roadway, time of day (peak vs. off-peak periods) and type of surrounding land use. The surrounding land use may include central business districts, shopping centers, residential, industrial and rural areas, etc.

Estimates of the percentages of vehicles operating in the hot and cold start conditions are needed to estimate vehicle exhaust emissions used in air quality analyses. An air quality analysis is required for Environmental Impact Statements for major federally funded construction and reconstruction projects. When these estimates are required for New Jersey roadways, the percentages for various functional classifications of roadways contained in the Data Analysis section of this report can be used. To use the results the roadway segment undergoing analysis is compared to the descriptions of the various groups of sites for the appropriate functional classification of roadway. The corresponding percentages for that group of sites whose description most closely represents the roadway segment undergoing analysis would be used. If the description of one of the groups of sites for the appropriate functional classification of roadway does not represent the roadway segment, then there is justification for using the "combined" percentages as contained in Table 3

of the Data Analysis section. These percentages were calculated from the weighted averages of all of the sites under a functional classification. This latter method of selecting hot and cold start percentages is valid to the extent that the percentages were derived from actual field measurements and are therefore, considered to be more accurate than values derived from judgement.

CONCLUSIONS BY STUDY ELEMENT

LITERATURE SEARCH

The variation of tailpipe emissions under actual driving conditions are not reflected by the 1978 Environmental Protection Agency (EPA) definitions of hot and cold starts. The EPA definitions of hot and cold starts are time based definitions. The 505 second reference time is that time that is convenient to change emission sample bags during laboratory vehicle engine emission measurements on vehicles being tested according to the Federal Test Procedure. By using discrete sample bags the emission factors thus obtained is an average for the 505 seconds.

Engine lubrication and cooling system temperatures can best be correlated with engine on time. An engine at ambient temperature that is turned on requires approximately ten minutes after the engine thermostat opens for the temperature of the fluids in the lubrication and cooling systems to stabilize provided engine load remains the same.

Engine temperature profiles can be determined by testing sample engines from the same family of engines from a manufacturer. Not all models of vehicles from a manufacturer must be tested in order to determine

engine temperature profiles. For example - a 318 cubic inch engine from a 1976 Dodge Dart is the same engine as the 318 cubic inch engine installed in a 1975 Plymouth.

Non-contact temperature instrumentation and systems can be used to determine vehicle temperatures provided certain conditions are met. Hand held non-contact temperature instruments respond to energy from targets 0.9" to 2" in diameter. Constant emissivity across the target area and knowledge of this value is required for accurate temperature determination. Larger non-contact systems (scanners) with liquid nitrogen cooled detectors can determine temperatures of larger areas provided the target emissivity(ies) are known and contact temperatures are available for reference.

VEHICLE OPERATING EXPERIMENT

Cold starts can be determined in the field by the measurement of the temperature of the engine oil in the oil pan via the dipstick tube provided the inserted thermocouple occupies the same position as that previously occupied by the tip of the dipstick. The temperature of the engine oil of a vehicle can be correlated to the EPA definitions of cold starts via experimentally determined engine oil temperature time relationships.

Hot starts cannot be determined in the field by the measurement of any external engine component, engine lubricating or cooling system temperatures. Engine temperatures quickly stabilize after engine turn on in the hot start condition. Hot starts may be determined in the field by the driver's estimate of engine on and off times.

Coolant cooled engines in 4, 6, and 8 cylinder configurations have different engine oil temperature time characteristics. Other factors affecting the engine oil temperature time profile are vehicle speed and ambient temperature.

EQUIPMENT SELECTION

Non-contact hand held temperature measuring instruments and liquid nitrogen cooled detector systems (scanners) cannot be used to measure vehicle engine temperatures in the field. The results of the scanner demonstrations suggests that a potential for correlation exists between EPA definitions of hot and cold starts and infrared surface emissions obtained by scanners. Contact temperature measurement equipment was selected for measuring engine oil temperature in the oil pan and coolant temperature via the top radiator hose. Stainless steel encased flexible type T thermocouple probes attached to Fluke Digital Thermometers and a Fluke 2240B Data Logger comprised the field data management system.

SAMPLING SCHEME DEVELOPMENT

A sufficient number of samples can be collected to obtain $\pm$.05 confidence limits at the 95% level under the worst conditions of 50% hot or 50% cold starts. A sample of 1440 vehicles was planned to be obtained for each of the six functional roadway classifications during the one year allocated to the field collection of data.

DATA COLLECTION, REDUCTION AND ANALYSIS

The percentages of vehicles operating in the hot and cold start condition are a function of functional classification of roadway, time of day

(peak vs off-peak) and type of surrounding land use. When estimates of hot and cold start percentages are required for New Jersey roadways, the percentages contained in the Data Analysis section of this report can be used.

RECOMMENDATIONS

The group percentages contained in the Data Analysis section should be used as hot and cold start percentages in air quality determinations for future environmental impact statements in New Jersey. If the descriptions of the roadway segment undergoing analysis differ from those of any of the groups listed under the same functional classification then the percentages contained in Table 3, "Summary of Combined Results," should be used.

In the event that hot and cold start data is collected in the future, the Vehicle Operating Experiment should be repeated provided the vehicle fleet changes significantly (vehicle sizes change thus new engine/transmission families are introduced) or if a different, faster method of collecting hot and cold start data is developed.

INTRODUCTION

All major federally-funded road construction and reconstruction requires an Environmental Impact Statement (EIS). Included in the EIS is a prediction of air quality resulting from any changes in traffic after the completion of construction. Part of this prediction is an emissions correction based on the percentages of cars and light trucks which will be operating in the "Hot Start" and "Cold Start" conditions. These conditions, defined by the Environmental Protection Agency [1] are in Appendix A. The resulting predictions of air quality are significantly affected by the percentages of hot and cold starts.

States use various methods to estimate hot and cold start percentages; within New Jersey, engineering judgment is used. However, because of their importance in the air quality prediction model, it was concluded that more accurate information was needed. This study was undertaken to provide this information. Statistically sound techniques were used for site selection and data analysis so that the percentages and their confidence limits could be determined with a high degree of accuracy for New Jersey roads.

Initially it was assumed that vehicle operating temperature could be used as an indicator of hot and cold starts, since it was believed that deviation from the normal vehicle operating temperature would necessarily place engine condition in one or the other category. Testing tailpipe emissions was not considered satisfactory because poor engine maintenance could cause emissions indicative of hot or cold start conditions even

though the engine temperature was stabilized. Furthermore, the EPA definitions do not accurately reflect the variation of tailpipe emissions under actual driving conditions primarily because they were derived from the conditions encountered during laboratory simulation of urban driving. Due to these facts, plus the relationship of operating temperature to time (time being the basis of the EPA definitions) it was decided to develop the study without any measurement of emissions. Accordingly, activities were directed to determining statistically accurate percentages of hot and cold starts for the following functional classifications of roadways:

1. Urban Principal Arterial;
2. Urban Minor Arterial and Collector;
3. Urban Local;
4. Rural Principal Arterial;
5. Rural Minor Arterial and Collector;
6. Rural Local.

These classifications comprise the entire road system in the State of New Jersey. They will be discussed more fully in the section on sampling scheme development and site selection.

The study was divided into five main elements, each one designed to provide a foundation for those following. The first was the literature search which was conducted in three main parts: a) the determination of a definition of operating temperature and related information b) an investigation of contact and non-contact temperature measuring equipment; c) a study of factors pertinent to developing a methodology for the study. The second element consisted of a vehicle operating experiment to determine

the best on-vehicle locations for testing for hot and cold starts, and the development of a data reduction process. The third element, demonstrations and comparisons of temperature measurement methods and equipment was carried out and equipment selected. Concurrently, the fourth element was development of a statistically sound sampling scheme, and the selection of data collection sites. The fifth element comprised field collection of data, data reduction, and data analysis which yielded the percentages of hot and cold starts for the six functional classifications of roadways.

LITERATURE SEARCH

OPERATING TEMPERATURE AND RELATED INFORMATION

Since no attempt was to be made to measure emissions, this part of the literature search was directed to defining the term "Operating Temperature." This term was intuitively understood, but for data collection purposes it was thought that an exact technically acceptable definition would be necessary and that this would result in practical temperatured-based definitions of hot and cold starts. The existing EPA definitions of these two terms are based on soak time (continuous off time before starting) and running time, neither of which can be accurately measured in the field. Concurrently, the problems of determining which automotive system(s) should be used to formulate the desired definitions, and also which should be instrumented for the Vehicle Operating Experiment were being researched. Last, an attempt was made to reduce the large and varied vehicle population to a workable size.

In the course of obtaining information to define operating temperature, numerous publications were examined, and engineering personnel from the Coordinating Research Council and the Ore-Lube Corporation, both in New York City, and the Ford Motor Company and the Society of Automotive Engineers in Detroit were consulted.

Two important results came from this portion of the literature search. The first was the following definition of operating temperature, and the fact that it was of necessity based on time rather than temperature.

Operating Temperature

The temperature occurring in the engine cooling and

lubricating systems ten minutes after the thermostat opens, assuming driving conditions remain substantially the same throughout. This temperature varies over a rather narrow range ($\pm 15^0$) during normal highway and city driving.

This definition came primarily from information in reference [2], and agreed with the intuitive concept based on experience. The second result was the elimination of certain systems, especially the exhaust and fuel systems, as valid indicators of hot and cold starts. At the same time, it became clear that the best indicators were the engine lubrication and cooling systems. References [2] and [3] were the primary sources of this information. Details of this portion of the literature search are contained in Reference [4].

An additional factor of this part of the literature search was the reduction of the very large and varied vehicle population in New Jersey to a more useable size in order to determine what vehicles to use in the Vehicle Operation Experiment. This was done by determining which engines had been used in American vehicles during the preceding 10 years, so that a sample of vehicles using certain engine types could be obtained for the Vehicle Operating Experiment. This eliminated the need for considering the several hundred combinations of vehicle makes and models.

TEMPERATURE MEASURING EQUIPMENT

In preparation for the investigation and comparison of temperature measuring equipment, a review of infrared physics was conducted. This information was used in the evaluation of the infrared temperature equip-

ment. A literature survey was conducted to determine potential suppliers, manufacturers, and users of such equipment. A list of 35 manufacturers and 3 users was obtained and each was contacted by mail for detailed specifications, reports or papers pertinent to project needs, and information on users' experiences. The information thus obtained was studied for the purpose of selecting potential items for demonstration.

Optical pyrometers and infrared film were shown to be unsuitable for the proposed use because of high temperature thresholds. Two general categories of non-contact measuring equipment were considered for use. The first was hand-held instruments. These were light-weight (less than four pounds) self contained, battery-powered units, which respond to targets from 0.9" to 2" in diameter, have variable emissivity controls in the range 0.2 to 1.0, and an internal reference to negate errors due to problems with the detector or the electronics of the unit. They do not require cooling by liquid nitrogen. Readout is either digital or by meter.

The second group comprised larger systems of various sizes, weights, and detector types. These are liquid nitrogen cooled. Readout is on a video display which is either in black and white or in color upon which an appropriate scale has been superimposed.

Contact temperature measuring equipment had been evaluated during a previous project. However, digital thermometers and recording equipment from the John Fluke Manufacturing Co. was investigated.

More complete information on this portion of the literature search can be found in reference [5].

METHODOLOGY FOR DATA COLLECTION

The literature search evolved into an ongoing element of the study, although the preceding sections were covered in separate reports. The final phase of the element led, in essence, to the field data collection method, via the Vehicle Operating Experiment.

In designing this experiment it was necessary to adhere to the requirements of the EPA definitions of hot and cold starts. The definitions were a direct result of the Federal Test Procedure for measuring emissions, which consists of collecting emission samples from the vehicles operating on a dynamometer in a manner considered to be a simulation of an urban trip. The definitions (see Appendix A) are therefore based not on actual field experience, but are a result of the fact that 505 seconds is a convenient point in the procedure at which to switch sample collection bags. Furthermore, no definitions were promulgated based on a simulated rural trip. Nevertheless, the EPA definitions stand as the criteria, since any changes would have invalidated most of the EPA efforts prior to 1978, concerning emissions. Accordingly, the Vehicle Operating Experiment sought to obtain data which could be used to develop criteria for determining the hot or cold start condition of vehicles sampled under the data collection element of the study. A more detailed account of this material can be found in Reference [6].

VEHICLE OPERATING EXPERIMENT

INTRODUCTION

The ultimate purpose of this element of the study was to determine what data was required to calulate the percentage of hot and cold starts from randomly selected vehicles at sites representing the six functional classifications of roadways in New Jersey. This was achieved through the collection of time-temperature data for selected test vehicles operated under controlled driving conditions over specific routes. The data thus obtained was analyzed, yielding those engine locations most indictive of the cold start condition, and the temperature ranges to be expected. It was also determined that hot starts could not be found through temperature measurement. Specifically this element was divided into five general tasks. The first was to select the vehicles to be used.

SELECTION OF VEHICLES

As already mentioned, the large and varied vehicle population was reduced to a more useable size by considering engine (gasoline) displacement only, which often remain the same year to year, thereby eliminating the need to obtain a sample representative of the hundreds of combinations of engines, transmissions, carburetors, etc. Even so, there were over 60 engine sizes used in the ten years preceding the experiment. Of these, 28 were represented by 32 vehicles used in this experiment. Included were 4, 6, V-6, and 8 cylinder engines. Some of the 4-cylinder cars were foreign-made, and with the exception of four, all vehicles had automatic transmissions. To a considerable extent, vehicle selection was dictated by the availability of New Jersey State fleet vehicles; rental units were

obtained to complete the range of engine sizes to be tested. A list of the vehicles used in this experiment is in Appendix B.

INSTRUMENTATION

The next general task was the instrumentation of each vehicle prior to the data collection process. Preliminary investigations of the usefulness of data from 43 different locations on a vehicle were conducted. Thermocouples were attached to points on the cooling system, engine, and the exhaust system. In addition, two were placed in the wheel wells, one on the grill, one on the hood, and one on a tire. Also, one was used for calibration and another for ambient temperature. About half of these points were eventually eliminated; up to 24 were retained, including the ambient and calibration thermocouples. Figure 1, pages 16 and 17 show a typical final thermocouple arrangement, used during the actual data collection portion of the experiment.

Thermocouples were mounted in various ways depending on location. In most instances, thermocouple tips were fastened in postion by using adjustable metal hose clamps, by epoxy, or by placing them under the heads of bolts already on the engine. In the case of immersion in fluids, the thermocouple wire was clamped in a way which left the end unencumbered so as not to restrict the flow around it.

Data from the thermocouples was recorded on a Leeds and Northrup 24-point recorder. This instrument had both high (0 - 1500^{0}F) and low (0 - 400^{0}F) ranges which operated simultaneously, allowing for the recording of temperatures from such disparate sources as oil, water, ambient air, and exhaust system points while giving acceptable definition

FIGURE 1

TYPICAL THERMOCOUPLE LOCATIONS

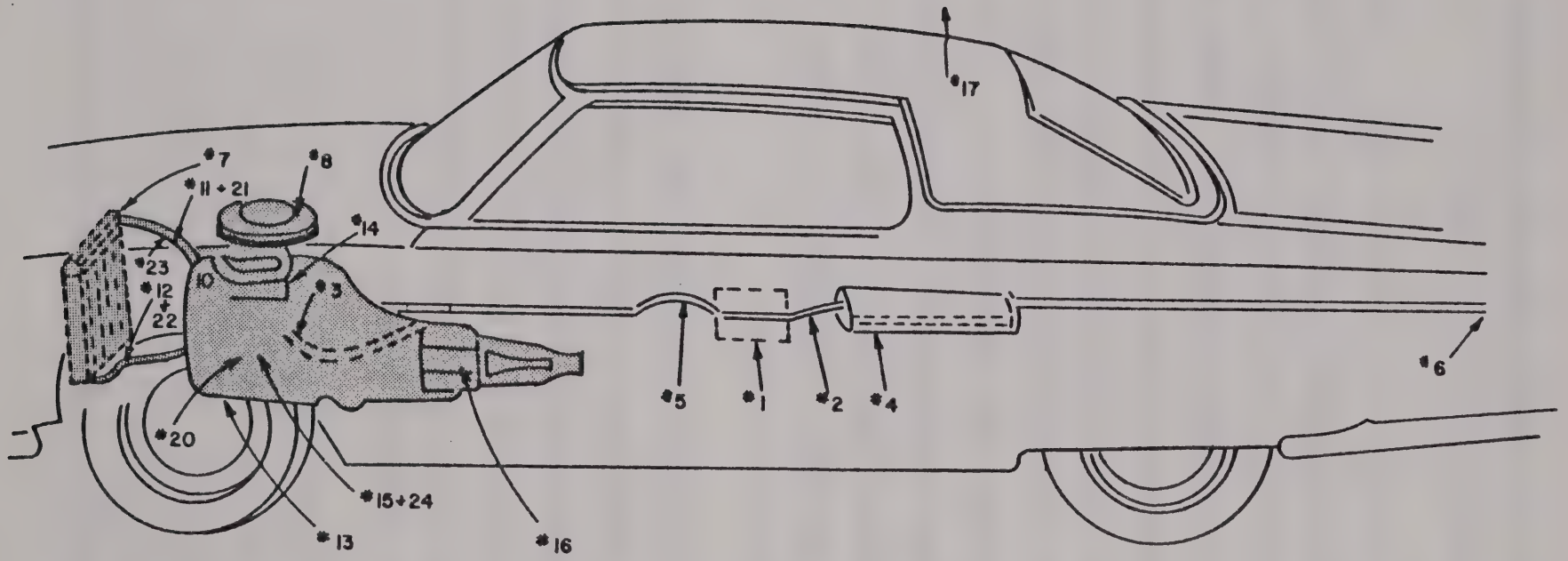


FIGURE 1 (cont.)

THERMOCOUPLE LOCATION #1-6 Type "J" Thermocouple - All Other Type "T"

#1 Catalytic Converter, outside skin

#2 Pipe directly after catalytic converter

#3 Pipe directly after exhaust manifold (heat riser spring)

#4 Muffler outside skin

#5 Pipe directly before catalytic converter

#6 Tail Pipe skin 6" from end

#7 Radiator temperature (epoxy connection, passenger side-inside top)

#8 Air intake (inside filter housing)

#9 Engine Head temperature (under valve cover, passenger side front inside)

#10 Engine Head temperature (under cover, driver side outside front)

#11 Water temperature (water from engine to radiator, two inches from thermostat immersed in water inside upper radiator hose)

#12 Water temperature (water from radiator to engine, immersed in water inside lower radiator hose) 2 inches from radiator

#13 Oil Pan, driver side (under pan mounting screw) front

#14 Engine Head temperature (under valve cover, driver side inside rear)

#15 Engine Oil (attached to end of oil dipstick, immersed in oil)

#16 Automatic Transmission (attached to end of dipstick, immersed in transmission oil)

#17 Outside ambient (six inches above roof top)

#18 Used for calibration

#19 Oil Pan skin (under pan mounting screw) passenger side front)

#20 Engine Oil - 1" deeper than #15 thermocouple

#21 Water temperature (same as #11)

#22 Water temperature (same as #12)

#23 Upper Radiator Hose (attached to outside wall by clamp, two inches from thermostat)

#24 Engine Oil (same as #15)

to each set of data points. AC power was supplied to the recorder by a Topaz inverter connected to the test vehicle battery.

DATA COLLECTION

The third task was the collection of data from the 32 test vehicles. After each vehicle was obtained, instrumented, tested, and allowed to soak for approximately four hours, it was subjected to a series of runs over prescribed courses. The recorder was activated a few minutes before the engine was started and run continuously throughout the test runs. For several test vehicles data was collected throughout the soak periods as well as during test runs. The vehicle operation followed each of the following controlled test conditions:

Test No. 1 - 35 mph (56.3 km/hr) constant speed - the test vehicles were operated at a constant 35 mph on a relatively level roadway and were considered to be operating under constant engine load.

Test No. 2 - 35 mph (56.3 km/hr) constant speed, variable terrain - the test vehicles were operated at a constant 35 mph on a roadway containing upgrade and downgrade sections, and were considered to be operating under variable engine load.

Test No. 3 - 55 mph (88.5 km/hr) constant speed - the test vehicles were operated at a constant 55 mph on a relatively level roadway, and were considered to be operating under constant engine load.

Test No. 4 - 55 mph (88.5 km/hr) constant speed, variable terrain - the test vehicles were operated at a constant 35 mph on a roadway containing upgrade and downgrade sections, and were considered to be operating under variable engine load.

Test No. 5 - Variable speed - the test vehicles were operated at variable speeds with periods of engine idle on a relatively level roadway, and were considered to be simulating vehicles operating on a typical suburban trip along roads with traffic interruption devices and varying speed limits. Therefore the engine load of each test vehicle was constantly changing.

Test No. 6 - Idle - the test vehicles were simply allowed to idle during the entire test. Since the vehicle speed was zero the engine load of each test vehicle was not varied as in Test Nos. 1 through 5 and was not affected by individual driving habits of operators.

Engine load was also varied by operating vehicles with and without the air conditioner operating, and by varying the roadway grade of the test courses, as previously discussed. The effects of ambient temperatures were determined by testing the same vehicles during winter and summer months.

DATA REDUCTION

The data obtained from the temperature recorder was reduced by plotting time-temperature curves for selected thermocouple locations; an example is found in Figure 2, pages 20 and 21. These curves are the result of plotting data from the points described in Figure 1.

DATA ANALYSIS

The fifth task included analysis of the data (in the form of graphs) for various factors. Generally, it was seen that the curves for Tests 1, 2, 3 and 4 were smooth enough so that it could be inferred that they all

FIGURE 2 - TYPICAL TIME - TEMPERATURE CURVES

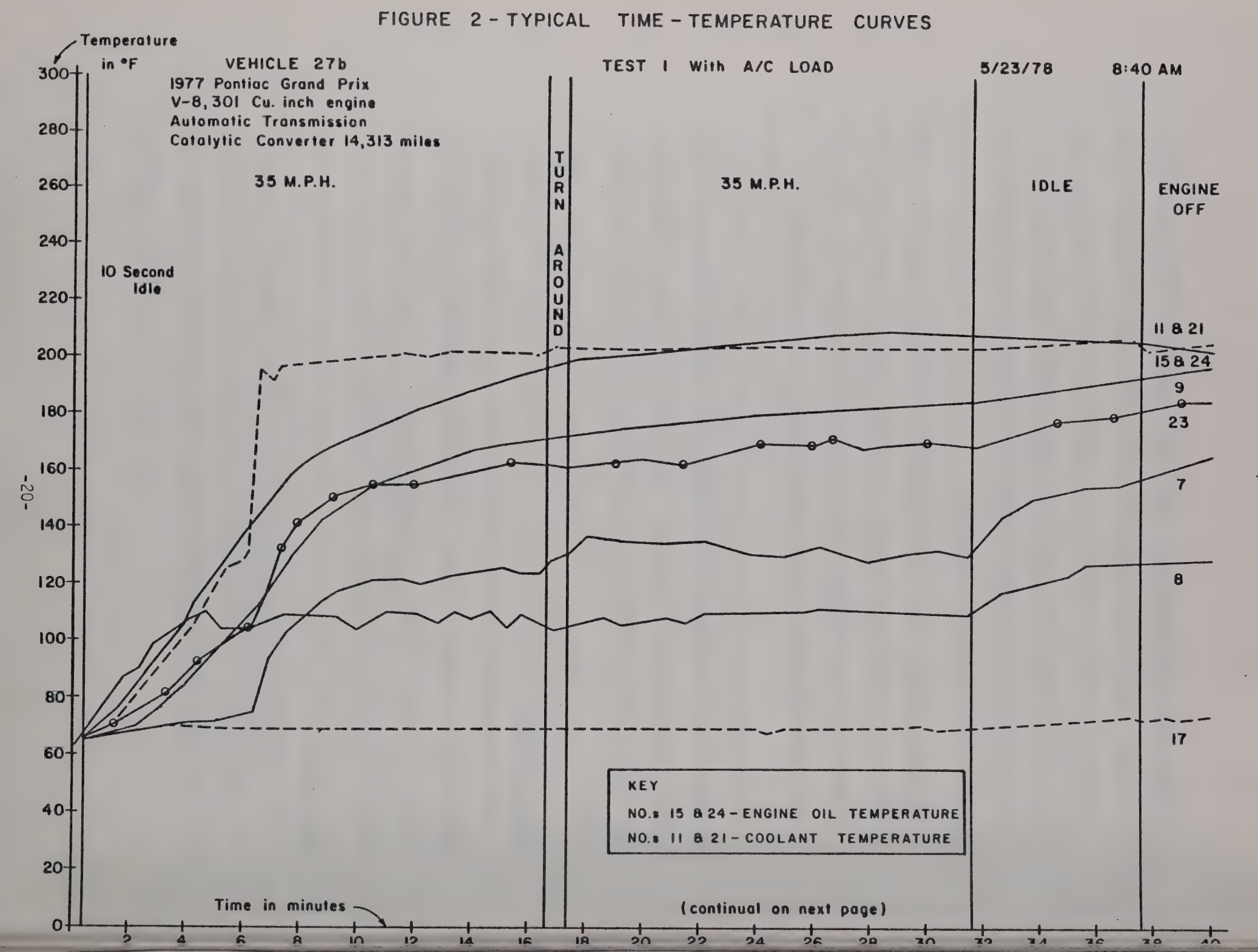
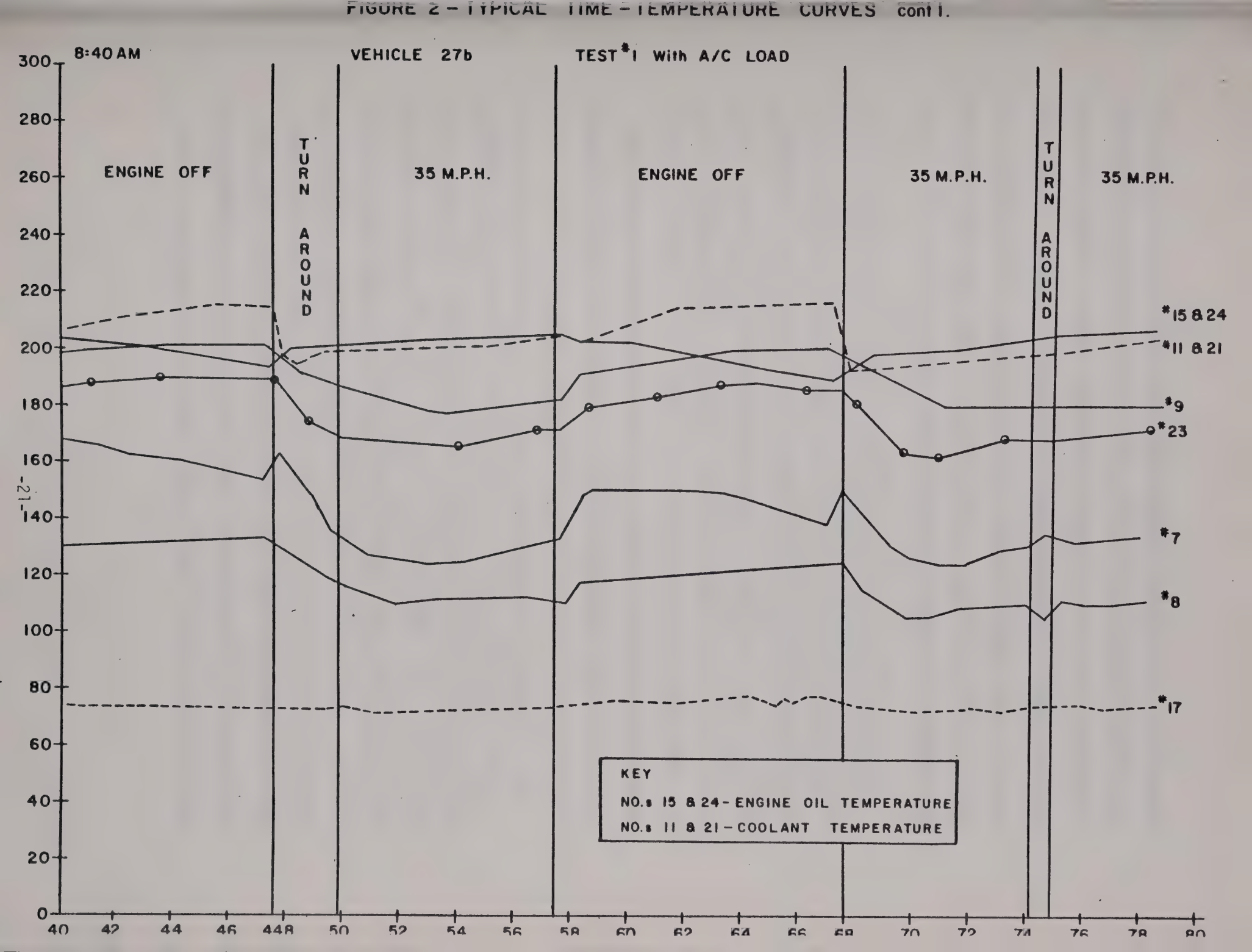


FIGURE 2 – TYPICAL TIME – TEMPERATURE CURVES cont'd.



minimized the effect of the idiosyncrasies of the test drivers. By implication then, data resulted from variables having to do with the roadways or the vehicles. It was found that varying the grade in Tests 1 and 2, and Test 3 and 4 had little effect on temperatures, thereby eliminating the only major roadway characteristic which might have contributed to variations. Factors which did affect vehicle temperatures were vehicle speed, number of cylinders, and ambient temperatures.

Temperatures varied widely from point to point on a vehicle, as also indicated in references [2] and [4]. Further indicated in these references and verified again in this experiment was the fact that the exhaust system is a poor indicator of engine operating condition because of high sensitivity to minor changes in driving conditions, while engine oil is a very good indicator, being relatively insensitive to rapid or slight changes in vehicle speed, engine load or driver operating characteristics. Therefore, further analysis of engine oil temperature data was performed to relate oil temperature to vehicle operating condition.

It was found that the cold start portion of the engine oil time-temperature data could be correlated to vehicle operating condition. Considering the EPA definitions of the hot and cold start operating conditions, the oil temperatures after 505 seconds of engine starting were examined. The oil temperatures were dependent on ambient temperatures, therefore an ambient temperature correction factor was determined by analyzing oil temperature data from vehicles tested during both warmer and colder months. Oil temperatures were then normalized using the ambient temperature correction. Since a wide variation in normalized oil tem-

peratures existed between 4, 6, and 8 cylinder engines for the different test conditions, distributions of these temperatures by test condition and number of cylinders were presented in tabular form. The temperature distribution tables of normalized oil temperatures after 505 seconds of engine starting formed the basis for the data reduction procedures used during the field data collection, reduction, and analysis element of the study. It was possible to determine the percentages of vehicles operating in the cold start condition at a field location by: taking oil temperature measurements in the field; correcting for ambient temperatures; and locating the corrected temperatures in the temperature distribution tables for the appropriate test condition or combination of conditions (which would correspond to field site conditions such as speed limit, traffic interrupting devices, etc.).

It was found that the hot start portion (the 505 seconds of operation after a short engine off period) of the time-temperature data for engine oil and the other temperature monitoring points could not be correlated to vehicle operating condition. In general temperatures had returned to stabilization within 200 to 300 seconds after vehicle starting. This precluded the use of a temperature measurement to determine hot starts during the field data collection element of the study. It was decided to obtain hot start information by questionnaire, using drivers' estimates of vehicle soak time and running time.

The entire Vehicle Operating Experiment is explained in detail in Reference [6].

EQUIPMENT SELECTION

This element of the study was undertaken concurrent with the Vehicle Operating Experiment and Sampling Scheme Development. As discussed in the Literature Search section, two types of equipment were considered for temperature data collection: infrared, and contact via special thermocouple probes.

In preparation for the assessment of infrared equipment, an extensive review of infared physics was conducted. Concurrently, inquiries were made of 35 manufacturers who were potential suppliers of equipment. These requests were made for detailed specifications of equipment which measures temperature in the ranges of 0^0F-400^0F and 1200^0F-1800^0F, as well as for copies of pertinent reports and technical papers.

Seven systems were demonstrated to assess their usefulness and applicability. They are listed below:

1. Barnes Instatherm;
2. Barnes ThermAtrace;
3. Williamson Model 220A;
4. William Wahl DHS-16;
5. AGA Model 750 with color monitor;
6. Inframetrics Model 510;
7. UTI Model 900.

The first four units are hand-held instruments; the remainder are larger stationary systems.

Demonstrations were preceded by a discussion of the unit's capabilities with a manufacturer's technical representative, followed by a laboratory demonstration. A second demonstration also was given, using vehicles instrumented for the Vehicle Operating Experiment. This consisted of comparing the infrared equipment readout for specific thermocouple locations with those from the recorder being used to collect the data for the Vehicle Operating Experiment.

All units were eventually rejected for use in the study. The Barnes Instatherm was rejected because it had a meter readout, while the ThermAtrace required a photographic print with an overlay to determine temperature, making for an unwieldly method of data collection. The Williamson 220A registered a $0^{o}F$-$44^{o}F$ difference from the temperatures found by thermocouples. This was due to non-uniform emissivity, non-planer targets, or other variations that resulted in emissivity changes from the base material. The Wahl instrument could not be used below $40^{o}F$ ambient, making it unfit for use about three months of the year. The demonstration of the AGA 750 was incomplete in that a fully instrumented test vehicle was not available. Therefore, temperature difference could not be determined. It was however possible to obtain a relative temperature profile. The remaining systems gave results which were not in agreement with those from the thermocouples. This was attributed to incorrect placement of the scan line over the thermocouple, and to the unknown combined emissivity of the different materials in the target area.

In general, infrared equipment could not be used to measure absolute temperatures because of the unknown combined emissivity of the target

because of oil, dirt, water and different materials, and the difficulty (or impossibility) of obtaining engine oil temperatures in the oil pan. Therefore, infrared equipment was eliminated for use in determining the hot and cold start operating conditions.

A pattern of infrared emissions obtained by a scanner from the sheet metal of a vehicle or the exterior surfaces of an engine indicates relative temperature differences. Since any one scanner frame is equivalent to over 250,000 temperature measurements, computerized image analysis would have to be considered for detailed analysis and comparison of the infrared emissions from test vehicles with those measured in the field. Proof that vehicular infrared emissions would be utilized to correlate to EPA definitions of hot and cold starts remains to be verified. The results of the scanner demonstrations suggests that a potential for correlation exists. Verification would have required a totally different Vehicle Operating Experiment and extended the study beyond its intended scope.

Contact temperature measurement equipment, including thermistors, platinum resistors, and high-temperature thermocouples had been evaluated by NJDOT Research personnel for an earlier project. Once it became certain that the measurement point was to be the engine oil in the sump, at the end of the dipstick, special thermocouple probes were obtained to insert into the dipstick tube. These probes were ungrounded, insulated by magnesium oxide, type T thermocouples, sheathed in 304 stainless steel, 1/16" and 1/8" diameter, 18", 36" and 60" long. These were ungrounded to eliminate ignition noise, which had presented problems when grounded pro-

bes were tested. Two sizes of probes were obtained. The five feet long probe, one-eight inch in diameter was for use with certain vans; the other was three feet long, one-sixteenth inch in diameter for use with all other vehicles. Both were calibrated at 140^0F, 180^0F, and 220^0F, traceable to the National Bureau of Standards (NBS). These probes were quite flexible to allow for insertion into the oil dipstick tubes of the various vehicles to be tested during data collection. The two sizes were interchangeable at the thermocouple wire end by virtue of a socket-plug arrangement. In addition, a third type of probe was obtained. This was an eighteen-inch long stiff probe to be used in taking the temperature of the outside of the upper radiator hose.

The oil and coolant hose probes were connected via thermocouple wire (calibrated as above) to Fluke 2160A digital thermometers and a Fluke 2240B Data Logger. This equipment met system selection criteria which is defined as worst case accuracy of $\pm$ 2°F over one year traceable to the National Bureau of Standards, printout of engine oil and coolant temperature along with air temperature, day of year, time of day, vehicle measurement number, the capability of obtaining data from two vehicles simultaneously, continuous monitoring of all channels of temperature data simultaneously, and no instance of equipment failure causing a delay or stoppage of the field tests. This system proved more than adequate in accuracy and overall response time (including operator time) during demonstrations. Moreover, it provided a printed record of all temperature data plus a constant monitor of the DC power supply voltage. This was obtained from heavy duty truck batteries which were connected to a Topaz sine wave inverter, which powered the Data Logger. Because of the

accuracy, speed of operation, availability of a printout, and its applicability to study needs, this arrangement was chosen for use.

Two full sets of equipment, each consisting of an inverter, six digital thermometers, one Data Logger, and a mounting rack were installed in a Dodge van. Batteries were installed in a battery box constructed in the rear of the van. This dualization of equipment, plus thermocouples, cables, and spares was deemed necessary to insure that a minimum of data would be lost due to equipment malfunction.

It was planned that in practice, two vehicles would be tested simultaneously. Two sets of probes (two for oil, two for the upper coolant hose) and cables were to be set up at stands about 50 feet apart, with a long (5-foot) oil probe kept ready at each station. The readout from each station would consist of the oil temperature, coolant hose temperature, and ambient temperature (from a third probe placed in the shade away from the work area). The signals from these three probes would be read by the digital thermometers (used to monitor the operation) and by individual Data Logger channels simultaneously. The data from each set of probes would be recorded by activating the printer, which would also record battery voltage to the inverter and interior ambient temperature in the van. Also to be recorded were the time, sequential day of operation, and sequential test vehicle number for that day. Thus an accurate ($\pm 1^{\circ}$ F), complete set of data could be otained for each test vehicle.

For further information on equipment selection, see reference [5].

SAMPLING SCHEME DEVELOPMENT

The objectives of this element were to determine the minimum sample size of vehicles needed at each functional roadway classification in order to obtain confidence limits of ($\pm$.05) and to select sites for data collection. Reference [7] gives the full details of this element.

SAMPLE SIZE DETERMINATION

To meet the first objective it was necessary to make a study of the statistical procedures involved. Accordingly, the binomial distribution was investigated. Since this distribution is a common one, there was a great deal of information available, and it was relatively simple to determine the sample size needed to obtain $\pm$.05 confidence limits at the 95% level. Although three categories of vehicles were to be considered (hot, cold, and stabilized), it was determined that the multinomial distribution need not be used. Neither was the hypergeometric distribution considered, since the vehicle population for any one functional classification was very large in comparison to any sample size which might be required.

However, the sample size needed to satisfy the theory also had to be compatible with the time limitations imposed by the study which in turn limited the number of sites which could be visited. Therefore, calculations based on the available information on projected on-site hours, available working days, and vehicle processing time were made, and it was found that in the one year allotted to data collection, a sample of 1440 vehicles could be obtained for each of the functional classifications. Even under "worst case" conditions of 50% hot (or cold) starts, this was

at least three times the sample size needed to obtain the desired confidence limits [8]. Hence, at this point it was assumed that the criteria could easily be met.

As implied in the preceding, site selection and sample size were interdependent. It was assumed that six sites per functional classification would be adequate to obtain the desired sample size. However, it was apparent from the outset that there would be variations of the percentages of hot and cold starts from site to site within the functional classifications since there might be generators of hot starts (such as shopping centers) and cold starts (such as residential areas) nearby. To adequately include these variations it was finally decided to subdivide certain classifications into those sites predominately affected by hot start generators, cold start generators, or neither. The subdivisions are listed below in Table 1.

TABLE 1

ROADWAY FUNCTIONAL CLASSIFICATION SUBDIVISIONS

URBAN	RURAL
Principal Arterial	Principal Arterial - no subclassification
1. Hot Start Generator	Minor Arterial and Collector
2. Cold Start Generator	1. Hot Start Generator
3. All Others	2. Cold Start Generator
Minor Arterial and Collector	3. All Others
1. Hot Start Generator	Local - no subclassificaiion
2. Cold Start Generator	
3. All Others	
Local-no subclassification	

As a result of the data reduction and analysis after completion of the field program, it was found that the subgroupings in Table 1 could not be used. The final grouping of sites under a functional classification were determined by grouping the sites by site descriptors and probable trip purpose. This eventually led to the final groupings of sites for which the hypothesis of homogeneity could not be rejected (See Data Analysis, page 46 and Appendix D).

In reassessing the resources available for field data collection it was decided to choose five sites and one alternate for each of the twelve categories in Table 1. Based on the assumption of 240 vehicles per site, this would yield a sample of 1200 vehicles per category which was still three times the amount needed to obtain the desired confidence limits.

SITE SELECTION

This task was accomplished in three steps. The first was the establishment of selection criteria, the foremost consideration being safety. Among the factors considered were line of sight, adequate area for parking project vehicles, adequate clearence between vehicles to be sampled and traffic lanes, non-interference with traffic flow, and avoidance of truck and equipment crossings, cattle crossings, fallen rock zones, public parks and playgrounds. The second criteria was adequate traffic to obtain a sample of 240 vehicles per site, for the proposed six days (two hours per day) of sampling at each site. Third was the immediate elimination of obviously unsuitable roads such as dead ends, dirt roads, alleys, and multi-lane roadways divided in one or both directions.

The second step was to randomly select sites from each of the 12 categories in Table 1, to insure that at least six (five and one alternate)

would be available after the criteria were applied. Accordingly, a program was written to randomly select road segments from the New Jersey road inventory file. Using the program a list of road segments was generated. The list of road segments was examined for compliance with the site selection criteria and about half of the segments did not meet the criteria.

The remaining road segments were then visited and inspected for compliance with the site selection criteria. Particular note was taken of sight distance, adequacy of parking for project vehicles, and other safety factors. In addition, an attempt was made to assess the traffic volume to determine if an adequate sample of vehicles could be obtained. An inspection of the area in the vicinity of the sites was also made. This led to a categorization, by engineering judgement, of sites having predominantly hot starts, cold starts, or neither according to what types of generators were found nearby.

In compliance with the selection criteria the first five sites in each of the categories in Table 1 would be retained for data collection. However, it was not possible to obtain five sites for each category, therefore, data collection started using a total of 50 sites.

FACTORS AFFECTING DATA COLLECTION

Two factors affected the hours during which data would be collected. First, air quality predictions were made for the peak hour and peak eight hour periods of the year for the roadway under study. Second, "worst case" carbon monoxide (CO) levels generally occurred during early morning hours because of meteorological conditions.

Since it was not feasible to collect the required amount of data at each of 50 sites during the peak hour and peak eight hour periods of the year, time periods during the day were chosen to be representative of peak hours and off-peak hours. It was decided that data collected during the morning rush hour (7:00 a.m. - 9:00 a.m.) would be representative of the peak hour data for the year, and data collected from 9:00 a.m. to noon or later would be representative of off-peak hour data. A combination of "peak" hour and "off-peak" hour data would then be representative of peak eight hour data for the year. Therefore, during data collection temperature measurements were made during the above mentioned time periods.

DATA COLLECTION, REDUCTION, AND ANALYSIS

DATA COLLECTION

Introduction

Hot and cold start data was to be collected from randomly selected light-duty vehicles which were to be stopped at sites throughout the state. Data was to include engine oil and upper radiator hose temperature, engine running and soak time, number of cylinders and whether or not unleaded gas was required. This last item was necessary because the definitions for hot starts and cold starts differentiated between vehicles with catalytic converters and those without. As previously established the cold start condition (as defined by EPA) could be established by temperature measurement, but the hot start condition could not. Therefore, two different methods of data collection were required. Data for determining cold starts was obtained by inserting a thermocouple probe into the engine oil via the dipstick tube. A second temperature was taken at the outside of the upper radiator hose, about two inches from the engine. The data was recorded by manually activating the equipment housed in the equipment van. Data for determining hot starts was obtained by interviewing the driver and recording his/her statements on the duration of engine running and soak times. In addition, the interviewer recorded the year, make, model, number of cylinders and whether or not the vehicle required unleaded gas, in order to differentiate between vehicles equipped with catalytic converters and those without.

Since it would be necessary to stop vehicles operating in normal traffic at various locations in the state a safety procedure was developed to

protect both the project personnel and the public. Assistance was received from state and local police in directing vehicles into the data collection area.

During the course of the study the projected on-site time had increased from the two hours assumed during the sampling scheme development to five or more hours, depending upon location, to allow for data collection during peak and off peak hours. Therefore, the projected number of visits to each site was reduced from six to three. Sites were arbitrarily numbered 1 through 50 and scheduled to be visited in sequence for three cycles. Sites which could not be visited because of weather conditions or other reasons were rescheduled for the end of the cycle. However, some of the Urban Local sites were visited five times or more to obtain a sufficiently large sample. Rural Local sites were not revisited after the third time. It was felt that an inordinate amount of time would be required to obtain the desired sample because of the very light traffic on these roads. A few of the original 50 sites were cancelled because police assistance was unavailable. Since it was essential to have this assistance to direct vehicles into the test area and for safety reasons, alternates were chosen at which such assistance was available. Eventually one site was cancelled and since no alternate was available, 49 rather than 50 sites were used.

Data Collection is discussed in full detail in reference [9].

Training

A. Office - The office phase of orientation and training comprised two days of lecture and discussion for the permanent five-man field crew

and all replacement personnel. Included in this was background information on the history and goal of the project, a discussion of the definitions of hot and cold starts familiarization with data collection equipment allowing each person to operate it for a short period, and a thorough discussion of data collection procedures. Safety was emphasized, and the role of the police discussed, with special note made of the fact that public cooperation was voluntary. This was to be made clear to all drivers and those who refused to participate were to be treated with all courtesy and allowed to leave the test area immediately.

B. Field - The first five days of field training consisted primarily of setting up and removing the safety equipment and data collection equipment in an empty field. Once everyone was familiar with the various set-up operations D.O.T. vehicles and drivers were used to simulate traffic conditions so that all personnel would have an opportunity to work at the different data collection duties.

The last two weeks of field training consisted of actual data collection at an experimental site on Interstate 95 in Ewing Township, with the assistance of the New Jersey State Police.

Safety

Of prime importance to the data collection process was the safety of project personnel and the motoring public. At most sites traffic was travelling at highway speeds so that maximum precautions were needed, both during the set-up and break-down of equipment, and during the data collection itself. Accordingly, a basic safety layout was designed using standard traffic cones and diamond-shaped, safety-orange signs. A typical

safety set-up for highway sites is shown in Figure 3. In a number of instances data was collected from low speed local roads. At these sites the safety layout was generally changed radically in order to conform to the locale. An integral part of safety was the use of police to select vehicles and direct them into the data collection area. Data collection was never performed without police assistance. The policeman on duty also advised the field supervisor to stop operations when he felt it was unsafe due to weather or traffic conditions.

Equipment

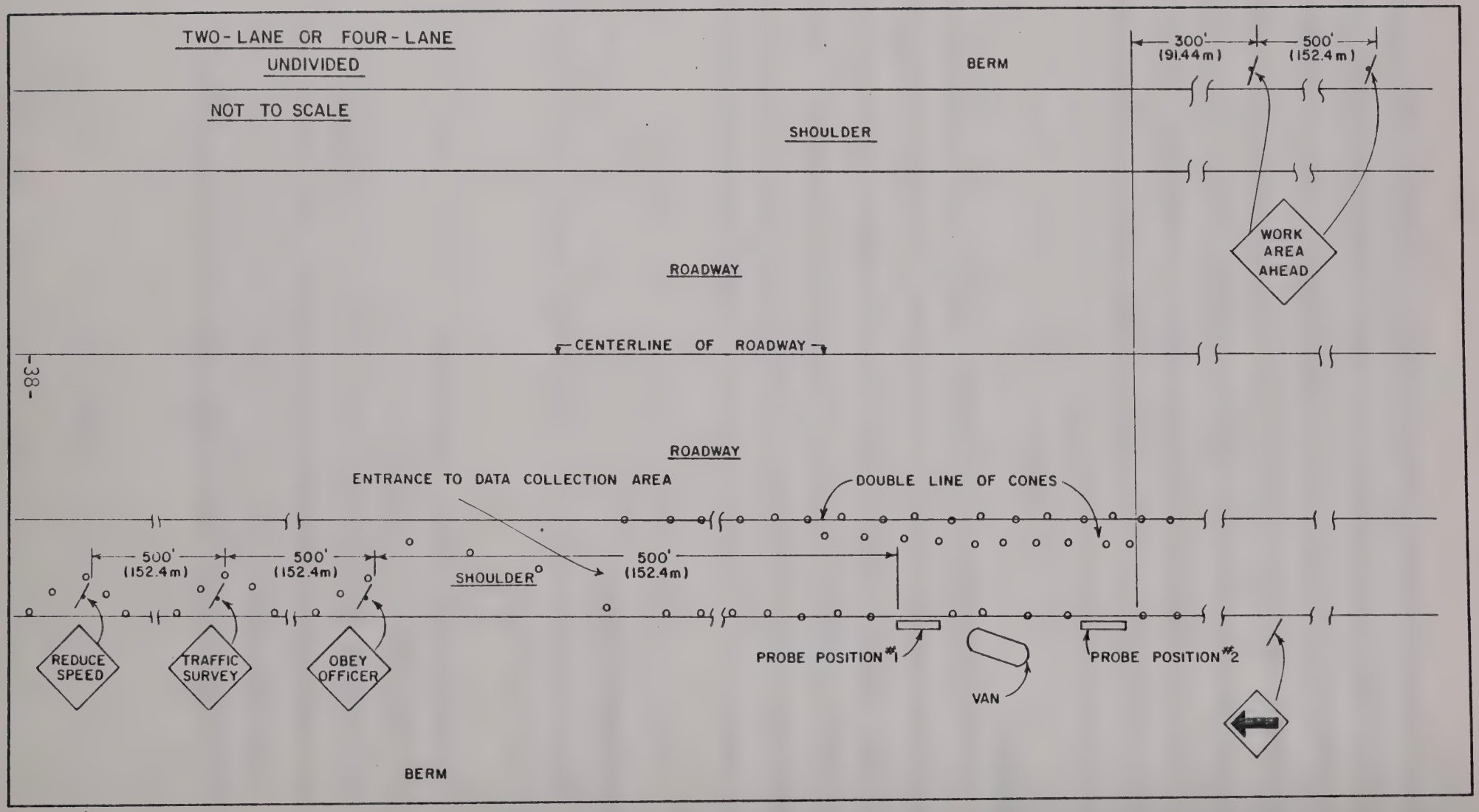
The basic measurement and recording equipment has been described in the Equipment Selection section of this report. As indicated in Figure 3, two probe stands were positioned alongside the shoulder of the roadway. This set-up enabled the sampling of two vehicles simultaneously. Digital thermometers for monitoring temperatures and data loggers were located in the equipment van. The data loggers provided permanent print-outs of data.

Data Collection Procedure

The data collection procedure was straightforward, consisting of the following basic steps:

1. Selection of a vehicle by the police;
2. Interviewing the driver;
3. Measuring and recording the oil and upper hose temperature;
4. Completion of paperwork and programming the data logger for the next vehicle;
5. Clearing the test area in preparation for incoming vehicles.

FIGURE 3 LAYOUT OF DATA COLLECTION AREA.



Data collection was generally performed by a five-man crew. Data collection began at 7 a.m. and proceeded to 9 a.m. without any scheduled break, so that as much as possible of the rush hour traffic could be sampled. Duties of the crew members were rotated every half hour. Data collection continued to noon or later depending on the site.

The temperature recording equipment was programmed for eight channels so that channels 0-2 recorded oil, upper hose and ambient temperatures respectively for probe stand 1; channels 3-5 were used analogously for probe stand 2; channel 6 recorded the ambient temperature in the equipment van; and channel 7 recorded the input voltage to the inverter. Figure 3 shows the probe stand locations. Each day at the beginning and end of data collection a program list was obtained which verified that each channel was in fact programmed as described. However, this list did not show the temperatures or input voltage. That data was printed out for all channels as a separate operation during data collection, a printout of which was also obtained prior to the start of data collection to insure that there were no discrepancies between the printout and the digital thermometers. Examples of a program list and a data printout are shown in Figure 4 and Figure 5, respectively. At the bottom of the printout in Figure 5, the vehicle sequential number (31), sequential day of data collection (137) and the time (08:43:23) are also indicated. Channel 6 (van interior ambient) was used only during cold weather.

Interview data was to obtain information on the hot start operating condition by utilizing a questionnaire. Figure 6 shows a typical completed questionnaire with attached printout. Pertinent information was

FIGURE 4

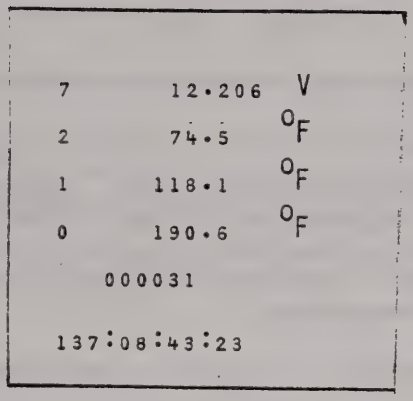
TYPICAL PROGRAM LIST

```
007    40,000   V
006    0000,4   °F
005    0000,4   °F
004    0000,4   °F
004    0000,4   °F
002    0000,4   °F
001    0000,4   °F
000    0000,4   °F

007

 000000
    00:10:00
076:06:30:00
```

This list verified that channels 0 to 6 are programmed to read out in °F from a type T thermocouple and that channel 7 is programmed to read to 40 volts. The number 007 in the lower part of the printout indicates that channel 7 is the monitor channel. The space occupied by 000000 is fixed data and is keyboard entered. The sequential vehicle number will appear in this location. The second to last line indicates the interval of time for automatic printout if set to operate in this mode. The last line shows the sequential day of operation (076) and (06:30:00) indicates the time of day in hours, minutes, and seconds.

FIGURE 5

TYPICAL TEMPERATURE DATA PRINTOUT



Channel	Data	Data Description
7	12.206 V	Input voltage to inverter
2	74.5 °F	Ambient temperature
1	118.1 °F	Upper hose temperature
0	190.6 °F	Oil temperature

FIGURE 6

COMPLETED QUESTIONNAIRE WITH PRINTOUT ATTACHED

```
7     12.209   V
2      74.8    OF
1      80.1    OF
0      79.2    OF

      000031
137:08:40:57
7     12.206   V
2      74.5    OF
1     118.1    OF
0     190.6    OF

      000031
137:08:43:23
```

Site No.	Date	Day	Time	Position	Car No.
16	7/27/79	1/3/7	8/42	0/1	3/1

A

morning
Good - afternoon I am _____ of the N. J. Department of Transportation. We want to take about 3 minutes of your time. We are collecting engine temperature information for use in air pollution studies. May we raise the hood of your car and make one engine oil temperature measurement via the dipstick tube and one upper radiator hose temperature measurement? B

1 - Yes - Please turn off your engine

Interviewer's Initials _____ No

Thank you, you may leave

We would like to ask you some questions:

	hrs	min
1. How long ago did you start your vehicle's engine (Make sure there were no stops where the engine was turned off)	0	50
2. How long was the engine off before starting it?	0	8 0 C
3. How long was the engine running before turning it off?	0	1 5

4. (Below 40°) Did you make use of an engine heater to heat the coolant or oil before starting on this trip? No - 0 Yes - 1

License Tag No.	State	Year	Make of Vehicle
401GSI	NJ	77	AMC

No Cyl	Model
6	PACER

Verify Unleaded Gas

No-0 (Yes-1)

Interviewer's Init. JF

Intials of Measurer ZZ

entered at the top and bottom of the questionnaire. Questions 1-3 were asked to obtain estimates of vehicle running and soak times. The printout obtained from the data logger was then attached to the questionnaire to facilitate data reduction. The upper portion shows the sequential vehicle number (031) and the time it entered the test area (08:40:57). The bottom shows the temperatures and other information depicted in Figure 5. The complete data collection procedure is contained in Appendix C.

During data collection 9,915 vehicles were processed. Data was not collected on 2,303 vehicles due to driver refusals, jammed or locked hoods, difficulty in obtaining oil temperatures, etc., resulting in data for a total of 7,612 vehicles. Table 2 indicates the number of vehicles for which data was obtained for peak and off-peak periods on the six functional classifications of roadways. A discussion of the reduction and analysis of this data follows.

DATA REDUCTION

Data reduction started about two months after data collection began and was continuous until completion of the field work. Data reduction procedures were established using the temperature distribution tables obtained from the Vehicle Operating Experiment element of the study. The data reduction procedures for field data are contained in Reference [9], however, a brief explanation follows.

Data reduction consisted of first examining the completed questionnaires and temperature print-outs for obvious errors. Since the definitions of hot and cold starts differ for catalytic and non-catalytic converter equipped vehicles, the questionnaires (with attached temperature

TABLE 2

NUMBER OF VEHICLES FOR WHICH DATA WAS COLLECTED

Functional Classification of Roadway	Number of Sites	Peak	Off-Peak	Total
Urban Principal Arterial	14	795	1438	2233
Urban Minor Arterial & Collector	9	520	1006	1526
Urban Local	6	278	435	713
Rural Principal Arterial	5	298	521	819
Rural Minor Arterial & Collector	12	826	1334	2160
Rural Local	3	61	100	161
Total	49	2778	4834	7612

print-outs) were separated for catalytic and non-catalytic equipped vehicles. As previously stated hot starts were determined from drivers' estimates of vehicle soak and running times. Questionnaires indicating soak times of less than one hour for catalytic converter equipped vehicles and less than four hours for non-catalytic converter equipped vehicles were potential hot starts. Questionnaires indicating running times of 505 seconds or less were considered as hot starts. Those indicating running times greater than 505 seconds were considered stabilized. Questionnaires indicating hot start and stabilized vehicles were separated by peak and off-peak hours and counted.

Questionnaires indicating soak times of one hour or more for catalytic equipped vehicles and four hours or more for non-catalytic equipped vehicles were potential cold starts. An ambient temperature correction was applied to each oil temperature reading on the print-outs corresponding to each questionnaire. The corrected temperatures were grouped for peak and off-peak hours and for 4, 6, and 8 cylinder engines. The corrected temperatures were then entered on data reduction forms which were prepared using the normalized 505 second temperature distribution results of the Vehicle Operating Experiment. The number of cold starts were determined directly from the forms. The percentages of vehicles operating in the hot start, cold start, and stabilized condition for each data collection site was also determined from the data reduction forms.

DATA ANALYSIS

Prior to calculating the percentages of hot and cold starts for groups of sites, the reduced field data was tested for homogeneity, the hypothesis being that the percentages (including stabilized) were all from the same population under each of the six functional classifications of roadways. The tests showed that the hypothesis should be rejected. When again tested, under the twelve categories in Table 1, page 30, the data failed to meet the criteria and the hypothesis was again rejected. The sites were then grouped by site descriptions and probable trip purpose under each functional classification. This eventually led to groupings of sites for which the hypothesis of homogeneity could not be rejected. Groups for peak and off-peak data under a particular classification do not often coincide, apparently because of changes in trip purpose. The detailed results for each functional classification, for peak and off-peak hours, for each group arrived at in the manner described above is contained on pages 50 to 72. Along with the percentages of hot and cold starts, site number, name, location, mile post, and general description of each group is included. In most cases the percentages of hot and cold starts were calculated during the testing; the confidence limits at the 95% level were calculated after analysis. These varied considerably from $\pm$1.1 to $\pm$19.9, depending upon sample size for the group and the percentage of hot and cold starts.

A detailed account of the data analysis is in Appendix D. It contains a description of the manner in which the groupings on pages 50 to 72 were arrived at through analysis of the site descriptions after the previous

hypothesis of homogeneity for all of the data from sites under a classification and then for all of the data from the sites under the twelve judgemental categories were rejected. Since peak and off-peak groups were not identical, peak and off-peak data were considered separately. Contained in this Appendix is the formula used to determine the 95% confidence limits as well as the references from which the tests for homogeneity and conficence limits were derived.

The Summary of Combined Results contained in Table 3 was calculated from the data from all vehicles under a functional classification. The data analysis showed that the combined data was not all from the same population except for urban local peak, rural local peak, and urban minor arterial and collector peak. While not all of the combined percentages are statistically valid, using these percentages is justified provided the roadway segment undergoing air quality analysis cannot be matched with the description of one of the groups of sites under the same functional classification. Examining the combined group percentages for each functional classification of roadways, the cold start percentages for each classification are consistenly higher than the EPA national averages of 21% for both peak and off-peak hours. The hot start percentages are consistently lower than the EPA national average of 27% for peak hours and in most cases lower for off-peak hours. Some trends in the results can also be seen. In all cases, cold start percentages for peak hours are higher than for off-peak hours and hot start percentages are lower for peak hours than for off-peak hours. This might be expected due to trip purpose during peak and off-peak hours. Since morning rush hours were assumed representative of peak hours, higher percentages of cold starts occurred.

Similarly, since morning (after 9 a.m.) and afternoon hours were assumed to be off-peak hours, higher percentages of hot starts occurred.

TABLE 3

SUMMARY OF COMBINED RESULTS

Major Classification	% Hot Starts		% Cold Starts	
	Peak	Off-peak	Peak	Off-peak
Urban Principal Arterial	6.5	21.1	46.8	29.9
Urban Minor Arterial and Collector	10.6	29.1	46.4	29.7
Urban Local	8.3	30.8	64	30.7
Rural Principal Arterial	3.0	8.6	36.9	23.2
Rural Minor Arterial and Collector	5.6	14.3	44.8	27.8
Rural Local	4.9	20.8	45.2	34.2

Note: Confidence limits are not listed

URBAN PRINCIPAL ARTERIAL - PEAK

GROUP I

Site Number	Site Name and Location
2	Rt. 24, Summit: 52.81 to 52.94*
8	I-287, Hanover Twp.: 35.04 to 35.11 (at the interchange with Route 10)
14	Passaic Avenue., Passaic: Terhune Avenue to Brook Ave.
25	Rt. 73, Waterford Twp.: 15.30 to 15.78
39	U.S. 22, Lapatcong Twp.: 225 to 3.21
45	Grove Street, Haddonfield: Redwood Avenue to Stream
47	Rt. 20F, Paterson: 1.69 to 1.78
49	Rt. 35, Bricktown: 9.09 to 9.12

Sites were in areas which had little or no commerical development. Sites 2, 14, 45, and 49 had complete residential development for at least a mile in one direction. All sites had completely developed commerical and residential areas within five miles.

Peak % Hot Starts: 6.0 $\pm$ 2.1 Peak % Cold Starts: 50.0 $\pm$ 4.4

Group II

Site Number	Site Name and Location
30	U.S. 46, Totowa: 57.10 to 57.40
33	U.S. 9, Sayreville: 127.95 to 128.75
36	Rt. 35, Middletown: 34.65 to 35.80

Sites were in areas which were completely developed commerically with shopping centers or malls, individual businesses, offices, etc. The com-

* milepost designation

merical area was surrounded by a well-established residential area in each case. Sites were about two miles from the CBD's of medium-sized cities. Roads were six and four-lane divided highways, with traffic being controlled by signals.

Peak % Hot Starts: 7.6 ± 3.6 Peak % Cold Starts: 40.9 ± 6.6

Group III

Site Number	Site Name and Location
20	I-80, Denville: 40.28 to 40.30 (County Route 513 interchange is within three miles of this site)

Site was located on a four-lane divided highway with limited access. There was no development of any kind fronting on the highway. The nearest residential and commerical development was about two miles from the site, becoming completely urban within three miles of the site. Peak traffic was sampled on the westbound side only, because the eastbound traffic was so heavy that it would have been extremely hazardous to sample it. The site was unique in that it paralleled U.S. 46 for about eight miles. Apparently the short-range traffic was on U.S. 46 while the long-range traffic was on I-80. This situation was not duplicated at any of the other sites.

Peak % Hot Starts: 4.4 ± 8.3 Peak % Cold Starts: 10.2 ± 9.7

GROUP IV

Site Number	Site Name and Location
42	Rt. 28, Scotch Plains: 18.50 to 18.84

Site was on a two-lane highway (with parking on both sides) which goes through the CBD's or other highly commercially developed areas of at least eight municipalities in about twelve miles. All of these are typical

northeast metropolitan area cities which are completely developed, with various types of development interspersed.

Peak % Hot Starts: 8.2 ± 6.3 Peak % Cold Starts: 51.9 ± 11.5

GROUP I, II, III, AND IV COMBINED

Peak % Hot Starts: 6.5 ± 1.7 Peak % Cold Starts: 46.8 ± 3.5

URBAN PRINCIPAL ARTERIAL - OFF-PEAK

GROUP I

Site Number	Site Name and Location
25	Rt. 73, Waterford Twp.: 15.30 to 15.78
39	U.S. 22, Lopatcong Twp.: 2.25 to 3.21
47	Rt. 20F, Paterson: 1.69 to 1.78
49	Rt. 35, Bricktown: 9.09 to 9.12

Sites were on four-lane divided highways which had little or no commercial development along them. Site 49 was fully developed residentially for at least three miles in either direction, but the other sites had no residential development along them. All sites had fully developed urban residential and commerical areas within five miles.

Off-peak % Hot Starts: 18.2 $\pm$ 3.6 Off-peak % Cold Starts: 30.2 $\pm$ 4.3

GROUP II

Site Number	Site Name and Location
30	U.S. 46, Totowa: 57.10 to 57.40
33	U.S. 9, Sayreville: 127.95 to 128.75
36	Rt. 35, Middletown: 34.65 to 35.80

Sites were in areas which were completely developed commerically with shopping centers or malls, individual businesses, offices, etc. The commerical area was surrounded by a well-established residential area in each case. Sites were about two miles from the CBD's of medium-sized cities. Roads were six and four-lane divided highways, with traffic being controlled by signals.

Off-peak % Hot Starts: 28.0 $\pm$ 4.5 Off-peak % Cold Starts: 25.5 $\pm$ 4.4

GROUP III

Site Number	Site Name and Location
2	Rt. 24, Summit: 52.81 to 52.94 (County Route 527 interchange is within 0.5 miles of this site)
20	I-80, Denville: 40.28 to 40.30 (County Route 513 interchange is within three miles of this site)

Sites were on six-lane divided highways with limited access. There was no development of any kind fronting on the highways. Complete urban commerical development was within three miles of the sites. Site 2 had complete residential development adjacent to the highway, easily accessible via the interchanges. Site 20 had partial residential development about two miles from the site.

Off-peak % Hot Starts: 8.7 ± 4.1 Off-peak % Cold Starts: 35.6 ± 6.9

GROUP IV

Site Number	Site Name and Location
42	Rt. 28, Scotch Plains: 18.50 to 18.84
45	Grove St., Haddonfield: Redwood Ave. to Stream

Sites were on two-lane roads (with parking on both sides) which passed through completely developed urban areas. At Site 42 there were mostly small businesses with a few homes for about a mile in either direction, changing to completely commerical with some light manufacturing. Most of the nearby streets were residential. The immediate vicinity of site 45 was a totally developed residential area, both along the road and on the adjacent streets. Development was almost all commerical along the road starting about a half-mile from the site, in one direction.

Off-peak % Hot Starts: 23.5 ± 5.0 Off-peak % Cold Starts: 29.6 ± 5.4

GROUP V

Site Number	Site Name and Location
8	I-287, Hanover Twp.: 35.04 to 35.11 (at the interchange with Route 10)

Site was on a six-lane divided highway with limited access. There was no development along the roadway, but complete urban commerical and residential development was about three miles away, via interchanges at Morristown and Parsippany-Troy Hills. The site was in a unique location in that it was on the only high-speed north-south highway 12 miles west of the Garden State Parkway.

Off-peak % Hot Starts: 4.3 ± 4.7 Off-peak % Cold Starts: 30.9 ± 10.8

GROUP VI

Site Number	Site Name and Location
14	Passaic Avenue, Passaic: Terhune Avenue to Brook Avenue

Site was on a two-lane road (with parking on both sides) in a fully developed residential area, which continued for at least a mile in one direction, before becoming commerical. Adjacent streets were also residential. In the other direction the area changed to commerical, with light manufacturing within one half mile.

Off-peak % Hot Starts: 35.0 ± 9.2 Off-peak % Cold Starts: 34.5 ± 9.2

GROUPS I, II, III, IV, V, AND VI COMBINED

Off-Peak % Hot Starts: 21.1 ± 2.1 Off-peak % Cold Starts: 29.9 ± 2.4

URBAN MINOR ARTERIAL AND COLLECTOR - PEAK

GROUP I

Site Number	Site Name and Location
3	Railroad Ave., Jersey City: Henderson St. To Hudson St.
9	Rt. 53, Parsippany-Troy Hills: 1.55 to 1.65
15	California Ave., Atlantic City: Arctic Ave. to Fairmont Ave.
21	Rt. 47, Millville: 41.23 to 41.70
31	Rt. 91, New Brunswick: 1.31 to 2.31
34	Conant St., Hillside: Valley View Road to Fairview Road
37	Rt. 48 Carneys Pt.: 0.32 to 0.35
40	Rt. 71, Spring Lake Heights: 2.43 to 2.53
43	Rt. 47, Deptford Twp.: 71.98 to 72.23

Sites were located on two-lane roads (with parking allowed on either side). Site location ranged from completely residential (Site 34), to completely industrial (Site 31), to residential-industrial-commerical (Site 3). Differences in site characteristics had little effect on hot and cold starts, since the data apparently was all from the same population.

Peak % Hot Starts: 10.6 ± 2.6 Peak % Cold Starts: 46.4 ± 4.3

URBAN MINOR ARTERIAL AND COLLECTOR - OFF-PEAK

GROUP I

Site Number	Site Name and Location
3	Railroad Ave., Jersey City: Henderson St. to Hudson St.
15	California Ave., Atlantic City: Artic Ave. to Fairmont Ave.
34	Conant St., Hillside: Valley View Road to Fairview Rd.
37	Rt. 48, Carneys Pt.: 0.32 to 0.35

Sites were in areas which had residential and business development adjacent to each other. Site 37 was more suburban than urban, being in a less densely populated area than the others.

Off-Peak % Hot Starts: 28.8 $\pm$ 4.4 Off-peak % Cold Starts: 34.2 $\pm$ 4.6

GROUP II

Site Number	Site Name and Location
21	Rt. 27, Millville: 41.23 to 41.70
31	Rt. 91, New Brunswick: 1.31 to 2.31
40	Rt. 71, Spring Lake Heights: 2.43 to 2.53
43	Rt. 47, Deptford Twp.: 71.98 to 72.23

Sites were along roads in areas which were almost completely developed commerically in the immediate site area, with the nearest homes ranging from one block to no more than one mile away. Fully developed residential and commerical areas were within two miles.

Off-peak % Hot Starts: 31.5 $\pm$ 4.1 Off-peak % Cold Starts: 24.6 $\pm$ 3.8

GROUP III

Site Number	Site Name and Location
9	Rt. 53, Parsippany-Troy Hills: 1.55 to 1.65

Site was in an area which was about 75% developed, mostly for homes, with a few small businesses within a few miles along the same road. Much higher commerical development was adjacent along Rt. 10, and full commerical and residential development within five miles in either direction along Rt. 53.

Off-peak % Hot Starts: 18.4 $\pm$ 7.8 Off-peak % Cold Starts: 37.1 $\pm$ 9.6

GROUPS I, II, AND III COMBINED

Off-peak % Hot Starts: 29.1 $\pm$ 2.8 Off-peak % Cold Starts: 29.7 $\pm$ 2.8

URBAN LOCAL - PEAK

GROUP I

Site Number	Site Name and Location
4	Borig Avenue, Lodi: Keasler Ave. to Hamilton Ave.
10	Frederick St,, Waldwick: Harrison Ave. to Franklin Tpk.
16	South Essex Ave., Orange: Central Ave. to Jackson Ave.
22	Arch St., Butler: Manning Ave. to Main St.
27	Monticello Ave., Newark: Marian Ave. to South Orange Ave.
50	Prescott Ave, Clifton: Main Ave. to Getty Ave.

Sites were located in completely developed urban areas in the metropolitan northeast section of the state. All streets were primarily residential with a few businesses and stores nearby, changing to completely commerical within two blocks. Site 27 was on a one-way street.

Peak % Hot Starts: 8.3 ± 3.2 Peak % Cold Starts: 64.0 ± 5.6

URBAN LOCAL - OFF-PEAK

GROUP I

Site Number	Site Name and Location
4	Borig Ave., Lodi: Keasler Ave. to Hamilton Ave.
10	Frederick St., Waldwick: Harrison Ave. to Franklin Tpk.
16	South Essex Ave., Orange: Central Ave. to Jackson Ave.

Sites were on roads which appeared to be on direct routes between roads of higher classification, and in areas which were primarily residential with a few small businesses in the site area. A small business district was within a few blocks in each case, with fully developed residential, shopping, and business areas within three miles.

Off-peak % Hot Starts: 25.7 $\pm$ 5.0 Off-peak % Cold Starts: 30.8 $\pm$ 5.3

GROUP II

Site Number	Site Name and Location
22	Arch St. Butler: Manning Ave. to Main St.
27	Monticello Ave., Newark: Marian Ave. to South Orange Ave.
50	Prescott Av., Clifton: Main Ave. to Getty Ave.

Site 27 was a one-way street by ordinance. For Sites 22 and 50 it was not possible to sample traffic on both sides of the street, making them one-way insofar as data collection was concerned. The side utilized had by far the greater amount of traffic in both cases. Each street was completely residential, with the site being located at the end of the street which was immediately adjacent to the local CBD.

Off-peak % Hot Starts: 40.8 $\pm$ 7.0 Off-peak % Cold Starts: 30.6 $\pm$ 7.4

GROUP I AND II COMBINED

Off-peak % Hot Starts: 30.8 ± 4.3 Off-peak % Cold Starts: 30.7 ± 4.3

RURAL PRINCIPAL ARTERIAL - PEAK

GROUP I

Site Number	Site Name and Location
6	Rt. 33, Millstone Twp.: 19.46 to 20.08
23	U.S. 9, Manalapan Twp.: 117.67 to 119.22

Sites were on four-lane divided highways, with traffic being controlled by signals. Areas were about 30% developed commerically and about 5% residentially for about two miles in either direction along the roadway. Increasing commerical and residential development started about two miles away in one direction, becoming fully developed within eight miles.

Peak % Hot Starts: 3.2 ± 3.1 Peak % Cold Starts: 45.5 ± 8.8

GROUP II

Site Number	Site Name and Location
12	I-295, Springfield Twp.: 49.24 to 49.96 (County Route 656 interchange is within three miles of this site)
28	U.S. 202, West Amwell Twp.: 0.79 to 0.88 (Route 29 interchange is 0.5 miles of this site)

Sites were on four-lane divided highways having limited access. There was no commerical or residential development along the roadway, and the nearest partially developed areas were about two miles away. Fully developed areas were within about five miles.

Peak % Hot Starts: 0.8 ± 1.5 Peak % Cold Starts: 32.8 ± 8.0

GROUP III

Site Number	Site Name and Location
18	Rt. 23, West Milford Twp.: 23.29 to 23.96

Site was on a four-lane divided highway, with traffic controlled by

signals. However, because of its rural setting and the lack of large population centers, there were few points of entry to the road other than at intersections. There was about 10% commericial development along the roadway for about two miles in both directions, and no residential development. Major development of both types was about eight miles away.

Peak % Hot Starts: 9.5 ± 8.9 Peak % Cold Starts: 24.5 ± 13.0

GROUP I, II, AND III COMBINED

Peak % Hot Starts: 3.0 ± 1.9 Peak % Cold Starts: 36.9 ± 5.5

RURAL PRINCIPAL ARTERIAL - OFF-PEAK

GROUP I

Site Number	Site Name and Location
12	I-295, Springfield Twp.: 49.24 to 49.96 (County Route 656 interchange is within three miles of this site)
28	U.S. 202, West Amwell Twp.: 0.79 to 0.88 (Route 29 interchange is within three miles of this site)
18	Rt. 23, West Milford Twp.: 23.29 to 23.96

Sites were on four-lane divided highways. Sites 12 and 28 were on limited access roads, Site 18 might be considered to have been on a limited access road because of its rural setting and lack of nearby large population centers, which greatly limited incoming traffic. The nearest fully developed residential and/or commercial, areas were within about five miles.

Off-peak % Hot Starts: 5.7 ± 2.6 Off-peak % Cold Starts: 19.0 ± 4.4

GROUP II

Site Number	Site Name and Location
6	Rt. 33, Millstone Twp.: 19.46 to 20.08
23	U.S. 9, Manalapan Twp.: 117.67 to 119.22

Sites were on four-lane divided highways, with traffic being controlled by signals. Areas were about 30% developed commerically and about 5% residentially for about two miles in either direction along the roadway. Increasing commerical and residential development started about two miles away in one direction, becoming fully developed within eight miles.

Off-peak % Hot Starts: 12.6 ± 4.3 Off-peak % Cold Starts: 28.7 ± 5.9

GROUPS I AND II COMBINED

Off-peak % Hot Starts: 8.6 ± 2.4 Off-peak % Cold Starts: 23.2 ± 3.6

RURAL MINOR ARTERIAL AND COLLECTOR - PEAK

GROUP I

Site Number	Site Name and Location
7	U.S. 130, South Brunswick: 76.22 to 78.60
13	Rt. 34 Colts Neck: 10.56 to 11.76
24	Rt. 18F, Colts Neck: 19.28 to 21.92
29	U.S. 322, Logan Twp.: 2.19 to 2.21
32	U.S. 130, Logan Twp.: 11.71 to 12.16
44	U.S. 40, Pilesgrove Twp.: 7.60 to 10.05

Sites were in areas which were mostly undeveloped, with a few businesses or homes within two miles. Urban areas were at least five miles from the site in each case.

Peak % Hot Starts: 1.5 ± 1.1 Peak % Cold Starts: 45.2 ± 4.4

GROUP II

Site Number	Site Name and Location
1	Rt. 47, Middle Twp.: 1.55 to 1.76
35	Federal City Road, Lawrence Twp.: Rt. 546 to Ewingville Rd.
38	Rt. 37, Lakehurst: 31.74 to 21.79
41	Rt. 526, Upper Freehold Twp.: Lakeview Dr. to railroad

Sites were in areas which were lightly developed for business and/or housing, changing to almost fully developed for both within about five miles, in at least one direction.

Peak % Hot Starts: 10.6 ± 4.0 Peak % Cold Starts: 61.8 ± 6.3

GROUP III

Site Number	Site Name and Location
19	U.S. 206, Branchville: 117.07 to 117.34

Site was in an area which was mostly undeveloped, just outside of town. There were few businesses and homes along the road for at least three miles in either direction, with the nearest urban area being over five miles away. The fact that it was not possible to sample the southbound traffic may account for the fact that the data from this site is from a different population.

Peak % Hot Starts: 17.4 ± 11.0 Peak % Cold Starts: 12.4 ± 9.5

GROUP IV

Site Number	Site Name and Location
46	Rt. 31, Raritan Twp.: 19.85 to 20.65

Site was on a four-lane divided highway in a completely rural area, changing to a completely developed commerical area within a mile. This commerical area consisted of shopping centers, individual businesses, offices, etc. Flemington and residential portions of Raritan Twp. bordered this commercially developed zone.

Peak % Hot Starts: 9.1 ± 6.4 Peak % Cold Starts: 30.7 ± 10.3

GROUPS I, II, III, AND IV COMBINED

Peak % Hot Starts: 5.6 ± 1.6 Peak % Cold Starts: 44.8 ± 3.4

RURAL MINOR ARTERIAL AND COLLECTOR - OFF-PEAK

GROUP I

Site Number	Site Name and Location
13	Rt. 34, Colts Neck: 10.56 to 11.76
24	Rt. 18F, Colts Neck: 19.28 to 21.92
29	U.S. 322, Logan Twp: 2.19 to 2.21
44	U.S. 40, Pilesgrove Twp.: 7.60 to 10.05

Sites were in areas which were mostly undeveloped, with few businesses or homes within two miles. Urban areas were at least five miles from the site in each case.

Off-peak % Hot Starts: 5.6 $\pm$ 2.1 Off-peak % Cold Starts: 25.0 $\pm$ 3.9

GROUP II

Site Number	Site Name and Location
1	Rt. 47, Middle Twp.: 1.55 to 1.76
35	Federal City Rd., Lawrence Twp.: Rt. 546 to Ewingville Rd.
38	Rt. 37, Lakehurst: 31.74 to 31.79
41	Rt. 526, Upper Freehold Twp.: Lakeview Dr. to railroad

Sites were in areas which were lightly developed for business and housing, changing to almost fully developed for both within about five miles, in at least one direction.

Off-Peak % Hot Starts: 19.5 $\pm$ 3.9 Off-peak % Cold Starts: 40.6 $\pm$ 4.8

GROUP III

Site Number	Site Name and Location
7	U.S. 130, South Brunswick 76.22 to 78.60
19	U.S. 206, Branchville: 117.07 to 117.34

Sites were in areas which were mostly undeveloped, with a few businesses or homes along the road for at least three miles in either direction. The nearest urban areas were over five miles away.

Off-Peak % Hot Starts: 15.1 ± 4.5 Off-peak % Cold Starts 20.7 ± 5.1

GROUP IV

Site Number	Site Name and Location
32	U.S. 130, Logan Twp., 11.71 to 12.16

Site was in an area which was mostly undeveloped, with a few businesses or homes for about a half-mile in either direction. The site was adjacent to the town of Bridgeport. The nearest urban area was at least five miles away.

Off-peak % Hot Starts: 15.4 ± 6.9 Off-peak % Cold Starts: 15.3 ± 6.9

GROUP V

Site Number	Site Name and Location
46	Rt. 31, Raritan Twp.: 19.85 to 20.65

Site was on a four-lane divided highway in a completely rural area, changing to a completely developed commerical area within a mile. This commerical area consisted of shopping centers, individual businesses, offices, etc. Flemington and residential portions of Raritan Twp. bordered this commerically developed zone.

Off-peak % Hot Starts: 28.2 ± 7.9 Off-Peak % Cold Starts: 22.3 ± 7.3

GROUP I, II, III, IV AND V COMBINED

Off-peak % Hot Starts: 14.3 ± 1.9 Off-peak % Cold Starts: 27.8 ± 2.4

RURAL LOCAL - PEAK

GROUP I

Site Number	Site Name and Location
5	Stuart Rd., Princeton Twp.: Great Rd. to Cherry Hill Rd.
11	Ervey Rd., Allamuchy: Quakerchurch Rd. to county line
17	Wood Dr., Union Twp., Hunterdon Co.: Rt. 579 to Cooks Cross Road

Sites were in areas where a few homes had been build on relatively large wooded properties. Adjacent areas consisted of farmland or unused land. All were within about six miles of suburban and/or urban residential and commerical development.

Peak % Hot Starts: 4.9 ± 5.4 Peak % Cold Starts: 45.2 ± 12.4

RURAL LOCAL - OFF-PEAK

GROUP I

Site Number	Site Name and Location
5	Stuart Rd., Princeton Twp.: Great Rd. to Cherry Hill Rd.
17	Wood Dr., Union Twp., Hunterdon Co.: Rt. 579 to Cooks Cross Rd.

Sites were on roads which seemed to be short cuts between roads of higher classification or more heavily travelled roads and led directly to areas of suburban and urban development.

Off-peak % Hot Starts: 23.1 ± 8.6 Off-peak % Cold Starts: 36.7 ± 9.9

GROUP II

Site Number	Site Name and Location
11	Ervey Rd., Allamuchy: Quakerchurch Rd. to county line

Site was in an area which was far more rural than the other two. Traffic passing the site was mostly from the few farms in the general area. Traffic from the few new homes adjacent to the site and from other residential areas did not have to pass the site in order to reach developed areas.

Off-peak % Hot Starts: 6.7 ± 12.6 Off-peak % Cold Starts: 19.0 ± 19.9

GROUPS I AND II COMDINED

Off-peak % Hot Starts: 20.8 ± 7.7 Off-peak % Cold Starts: 34.2 ± 9.0

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APPENDIX A

HOT AND COLD START DEFINITIONS

The following definitions are from reference [1].

Hot Starts

1. For a catalytic converter equipped vehicle which has had an engine-off period of less than one hour, the hot start condition exists for the first 505 seconds of operation after engine restarting.
2. For a non-catalytic converter equipped vehicle which has had an engine-off period of less than four hours, the hot start condition exists for the 505 seconds of operation after engine restarting.

Cold Starts

1. For a catalytic converter equipped vehicle which has had an engine-off period of at least one hour, the cold start condition exists for the first 505 seconds of operation after engine restarting.
2. For a non-catalytic converter equipped vehicle which has had an engine-off time of at least four hours, the cold start condition exists for the first 505 seconds of operation after engine restarting.

Calculation of composite exhaust emission factors using the complete Federal Test Procedure (FTP) method is given by the following which is taken from reference [1].

"Enpstwx = SUM (Cipn*Min*Ripstwx*Aip*Ip*Uipw*Hip)

where all lower case letters are subscripts and:

SUM ( ) = summation over model year (i), from the calendar year for which emission factors are being calculated (i=n) the calendar year 19 years previous (i=n-19).

Enpstwx = Composite emission factor in gm/mi for calendar year n, pollutant p, average speed s, ambient temperature t, fraction cold operation w, and fraction hot start operation x.

Cipn = The FTP (1975 Federal Test Procedure) mean emission factor for the ith model year light-duty vehicles during calendar year n, and for pollutant p.

Min = The fraction of annual travel by the ith model year light duty vehicles (LDV) during calendar year n.

Ripstwx = The temperature, speed, and hot/cold correction factor for the ith model year LDVs for pollutant p, average speed s, ambient temperature t, fraction cold operation w, and fraction hot start operation x.

Aip = The air-conditioning correction factor for the ith model year LDVs, for pollutant p.

Lp = The vehicle load correction factor for pollutant p.

Uipw = The trailer towing correction factor for the ith model year LDVs, for pollutant p, and for fraction of cold operation x.

Hip = The humidity correction factor for the ith model year LDVs, for pollutant p."

Computation of all factors for the complete composite exhaust emission factor equation has been computerized and is available from EPA.

APPENDIX B

LIST OF VEHICLES USED IN VEHICLE OPERATING EXPERIMENT

NUMBER	LICENSE	MAKE	MODEL	YEAR	CYLINDERS	IN^3 (CM^3)	EXHAUST	A/C	TRANS.	MILEAGE
01*	TD-9194	Plymouth	Fury	1969	6	225(3687)	Std.	No	Auto.	91,000 101,000
02*	TD-0579	Plymouth	Fury	1973	8	318(5211)	Std.	No	Auto.	47,932
03	TD-0773	Internatl.	Travelall	1975	8	392(6429)	Std.	No	Auto.	22,728
04	TD-4284	GMC	Handi-Van	1967	8	283(4638)	Std.	No	Std.	98,000
05	TD-0453	Rambler	Ambassador	1968	8	290(4752)	Std.	No	Auto.	67,000
06*	TD-0448	Plymouth	Suburban	1973	8	360(5899)	Std.	No	Auto.	52,000
07*	TD-0588	Ford	Custom 500	1974	8	400(6555)	Std.	Yes	Auto.	52,896
08	TD-0504	Chrysler	Newport	1971	8	383(6276)	Std.	Yes	Auto.	57,000
09	TD-4354	Ford	Econo Van	1973	8	302(4947)	Std.	No	Auto.	30,400
10	TD-9539	Plymouth	Sedan	1974	6	198(3245)	Std.	No	Auto.	57,814
11*	TD-0628	Chevrolet	Carry All	1971	6	250(4097)	Std.	No	Auto.	58,143
12	TD-4981	Dodge	Pick-up	1975	6	225(3687)	Cat.	No	Auto.	5,677
13	TD-0682	GMC	Suburban	1976	8	350(5735)	Std.	No	Auto.	32,143
14	TD-4217	Ford	Econoline	1976	8	351(5752)	Std.	Yes	Auto.	25,396
15	SGR-819	AMC	Hornet	1972	6	232(3802)	Std.	No	Auto.	70,020

*Vehicles tested in both warmer and colder months. A/C - Air Conditioning Load: TRANS. - Transmission Type

APPENDIX B

NUMBER	LICENSE	MAKE	MODEL	YEAR	CYLINDERS	IN^3 (CM^3)	EXHAUST	A/C	TRANS.	MILEAGE
16*	SGM-840	Plymouth	Station Wag.	1975	8	400(6555)	Cat.	No	Auto.	15,603
17*	SGM-722	Plymouth	Fury	1973	8	440(7210)	Std.	Yes	Auto.	77,116
18*	TD-0482	Dodge	Aspen	1977	6	225(3687)	Cat.	No	Auto.	120
19	SGP-553	Ford	Pick-up	1967	6	240(3933)	Std.	No	Std.	32,573
20	SGM-752	Ford	St. Wag. Pinto	1972	4	122(2000)	Std.	No	Auto.	42,142
21	593-HZD	Ford	Pinto	1978	4	140(2294)	Cat.	No	Auto.	1,681
22	606-EIU	Chevrolet	Camaro	1977	8	305(4998)	Cat.	Yes	Auto.	20,914
23*	542-HKU	Chevrolet	Chevette	1978	4	98(1606)	Cat.	No	Auto.	1,842
24	723-EIU	Oldsmobile	Cutlass	1977	8	260(4261)	Cat.	Yes	Auto.	16,464
25	110-CZI	Pontiac	Sunbird	1977	4	153(2500)	Cat.	No	Auto.	6,852
26	648-GGP	Pontiac	Ventura	1977	V-6	231(3785)	Cat.	Yes	Auto.	13,763
27*	773-HYV	Pontiac	Grand Prix	1977	8	301(4933)	Cat.	Yes	Auto.	10,155
28	ALZ-425PA	Toyota	Corolla	1978	4	97(1588)	Cat.	No	Auto.	3,069
29	SGR-879	AMC	Hornet	1972	6	225(3687)	Std.	No	Auto.	64,712
30	771-EDA	VW	Rabbit	1978	4	97(1588)	Cat.	No	Auto.	3,100
31	466-IME	Honda	Civic	1978	4	91(1488)	Std.	No	S.A.	1,292
32	A14446APA	Datsun	210-GX	1977	4	85(1397)	Std.	No	Std.	10,503

*Vehicles tested in both warmer and colder months. A/C - Air Conditioning Load: TRANS. - Transmission Type

APPENDIX C

DATA COLLECTION PROCEDURE

The following is the routine used for data collection during the study:

1. The equipment operator signalled the interviewer that he was ready to record temperature data.
2. The interviewer signalled the policeman by raising one or two arms to indicate the number of cars to be directed into the data collection area.
3. As each car entered the ramp to the data collection area, the equipment operator obtained a printout showing the time, sequential vehicle number, and the probe temperatures. This served in part to indicate the length of time it took to process each vehicle and was a continuing check on the correlation of the digital thermometers and the Data Logger.
4. As each car approached, the dirver was directed to the proper location by the probe man (the temperature measurer).
5. Once the vehicle was in position, the interviewer greeted the driver, briefly explained the reason for stopping him, and requested his cooperation.
6. If the driver refused to cooperate for whatever reason, he was thanked for his time and allowed to leave.

6a. The interviewer noted the driver's refusal and reason on the questionnaire and gave it to the equipment operator who stapled it to the printout.

6b. The equipment operator entered the new sequential vehicle number in the program, and signalled the interviewer that he was ready for another vehice (or vehicles).

6c. The interviewer again signalled the policeman, to restart the cycle.

Alternately,

7. If the driver agreed to cooperate, the interviewer asked him to shut off the engine and release the hood latch. He then signalled the probe man to open the hood.
8. The interviewer then obtained the information to complete the questionnaire, and brought the completed questionnaire to the equipment operator in the van.
9. Concurrent with step 8, the probe man performed the following;
   a. Opened the hood;
   b. Removed the dipstick;
   c. Compared the dipstick length and probe and adjusted a probe stop, so that the probe would go no deeper than the dipstick;
   d. Inserted the probe into dipstick tube;
   e. Positioned second probe on the water hose and signalled equipment operator that both probes were in position;
   f. Removed the probes when equipment operator signalled that the data had been recorded, replaced the dipstick, closed the hood and informed the driver that the measurement was completed.

Occasionally the probe man rejected a vehicle because the hood could not be opened, the oil probe could not be inserted, etc. In this case he informed the interviewer, who made a note on the questionnaire to explain the lack of recorded temperature data.

10. Concurrent with step 9e the equipment operator carried out these operations;
    a. Indicated to probe man that he had received the ready signal;

b. Observed oil temperature on the digital thermometer. When the oil temperature remained constant for approximately seven seconds the equipment operator obtained a printout.

c. He then signalled the probe man that a printout had been obtained.

d. The two printouts were stapled to the questionnaire, which was placed in its designated pile. See Figure 6, page 42 for a completed questionnaire with printouts.

e. The new sequential vehicle number was entered in the Data Logger, and the equipment operator signalled the interviewer that he was ready for the next cycle.

When two probe stands were in use the equipment operator followed the same routine regarding both, but of course it was necessary to complete measurements and paperwork on both vehicles prior to his indicating readiness.

In addition to the duties described, the equipment operator constantly monitored the digital thermometers as a means of locating trouble in the probe circuits. An open circuit in the thermocouples was indicated by a flashing temperature display of $-328^{o}F$. A stabilized thermocouple scanning ambient temperature (not inserted into the oil or touching a coolant hose) should indicate ambient temperature.

APPENDIX D

DATA ANALYSIS PROCEDURE

Introduction

The reduced field data was analyzed to determine the percentages of hot and cold starts for each functional classification of roadway. This was accomplished in three steps. First, the data was tested to determine if it was all from the same population, within each classification. Second, the percentages were calculated. Third, the confidence limits were calculated for each percentage.

Testing for Homogeneity

As a matter of standard practice, any data to be analyzed should first be tested for homogeneity. In this instance the test was applied to the proportions (percentages) of hot and cold starts, the hypothesis being that in each case all of the data was from the same population. That is, the proportion of hot (or cold) starts at all sites within a certain functional classification (or category thereof, see Table 1, page 30) was from the same population as every other proportion within the same classification (or category).

In testing the hypothesis of homegeneity, an r x 2 contingency table was formed to determine chi-squared values. The format used can be found in reference [10], page 434. Each row comprised the number of hot starts and all others, or the number of cold starts and all others, or the number of stabilized and all others at a particular site. The test was therefore performed three times for the total of r sites for the peak hour data, and three times for the total of r sites for the off-peak period data. With the exception of the peak hour data for the Urban Minor Arterial and Collector,

Urban Local, and Rural Local classifications, at least one (and sometimes all) of the chi-squared values from the r x 2 tables required that the hypothesis of a common population be rejected. Since the categories of hot-other, cold-other, and stabilized-other were not independent, the rejection of any one resulted in the rejection of all. Thus in nine out of twelve instances (three peak and six off-peak), the data collected for all of the sites under a specific functional classification was shown to be from more than one population.

As a result of the above, it was decided to test the data from the subdivisions of the functional classifications for homogeneity, as a first attempt to discover how to group the sites into collections which would have data from the same population. This also resulted in the rejection of the hypothesis. This led to a rather detailed examination of the characteristics of the site locales, for the purpose of finding groups of sites within each functional classification which had common characteristics and then testing the data from those sites using the same method as before. Such factors as the number of lanes, whether or not the roadway was divided, the type of development along the road and within certain distances of the site, the distances to fully developed areas and central business districts the location of the site in relation to roads of equal or higher classification, and the probable purposes for which the road was being used were all considered in arriving at the groupings under each functional classification. The factor of probable usage was based on a general knowledge of the site area and on information gleaned from interviewing the drivers for hot start information. While there was no actual measured data to be considered, this information did provide some insight into the initial formation of the groups of sites.

Peak and off-peak groups often did not coincide, probably because the usage changed considerably from peak to off-peak hours judging from the information available. In addition, there were some individual sites which could not be included in the larger groups, nor was it possible to collect them to form groups of their own. This presented no problem however, since the characteristics of all groups, including those with only one site, were described so that each was clearly differentiated from the others.

Percentages of Hot and Cold Starts

In the course of applying the chi-squared test to determine homogeneity, it was necessary to calculate the percentages of hot and cold starts for each of the groups. Therefore, no further work was necessary for this purpose, once it had been determined that the hypothesis of a common population for the group could not be rejected. Since this test was not applied to groups containing data from only one site, the percentages had to be calculated for each of these separately.

Confidence Limits

Each percentage of hot and cold starts was reported together with its 95% confidence limits. These were calculated using the formula

$$\delta^* = \sqrt{p} \cos (\arcsin \sqrt{p}) \sin \frac{U_{\alpha/2}}{n}$$

Here p = percent hot (cold) starts, $U_{\alpha/2}$ is the lower limit of the standard normal distribution at the 95% confidence level, and n = the total sample size for the group. The derivation of this formula can be found in reference [11], pages 61 and 62. This method was used for calculating the confidence limits for all groups, including those containing only one site.

The formula cited is a result of manipulating the expression

$$n \simeq \left[\arcsin \left(\frac{U_{\alpha/2}}{\sqrt{p}\cos(\arcsin\sqrt{p})} \right) \right]^2$$

which was used to determine the appropriate sample size necessary for each functional classification, (Reference [7]). In obtaining the confidence intervals by this method, the questions of "large" and "small" p and n are eliminated.

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